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[LIST OF ARTICLES TO BE SUBMITTED]

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[Number of General Authorization]		0018106

[NAME OF DOCUMENT] Claims

[Claim 1]

Electrical steel sheet remarkably superior in magnetic properties characterized by containing, by mass%, C: 0.040% or less, Si: 0.2 to 3.5%, Mn: 0.05 to 3.0%, P: 0.30% or less, S: 0.040% or less, Al: 2.50% or less, Cu: 0.6 to 8.0%, N: 0.0400% or less, and a balance of Fe and unavoidable impurities and containing in the steel a metal phase comprised of Cu of a diameter of 0.01 μm or less.

[Claim 2]

Electrical steel sheet remarkably superior in magnetic properties as set forth in claim 1 characterized by further containing, by mass%, one or more of Nb: 0.02% or less, Ti: 0.010% or less, B: 0.010% or less, Ni: 2.5% or less, and Cr: 10.0% or less.

[Claim 3]

Electrical steel sheet remarkably superior in magnetic properties as set forth in claim 1 or 2 characterized by further containing, by mass%, one or more of Mo, W, Sn, Sb, Mg, Ca, Ce, and Co in a total of 0.5% or less.

[Claim 4]

Electrical steel sheet remarkably superior in magnetic properties as set forth in any one of claims 1 to 3 wherein a number density of the metal phase comprised of Cu present in said steel is $20/\mu m^3$ or more.

[Claim 5]

Electrical steel sheet remarkably superior in magnetic properties as set forth in any one of claims 1 to 4 wherein said steel sheet has an average size of crystal grains of 30 to 300 μm.

[Claim 6]

A method of production of electrical steel sheet remarkably superior in magnetic properties characterized by producing a product sheet from steel comprised of the ingredients as set forth in any of claims 1 to 3 during the

process of which holding it at a temperature range of 300°C to 720°C for 30 seconds or more for heat treatment.

[Claim 7]

A method of production of electrical steel sheet remarkably superior in magnetic properties as set forth in claim 6, characterized by, as said heat treatment, holding at a temperature range of 300°C to 720°C for 30 seconds or more in a cooling process from a temperature range of 750°C or more in a final heat treatment process.

[Claim 8]

A method of production of electrical steel sheet remarkably superior in magnetic properties as set forth in claim 6 or 7, characterized by, after the heat treatment, not holding in a temperature range over 800°C for 20 seconds or more.

[Claim 9]

Electrical steel sheet remarkably superior in magnetic properties as set forth in any one of claims 1 to 3 characterized in that, after an electrical part is worked, then heat treated for hardening, a metal phase comprised mainly of Cu present in the steel has a number density of 20/μm^3.

[Claim 10]

Electrical steel sheet remarkably superior in magnetic properties as set forth in any one of claims 1 to 3 and 9 characterized in that, after an electrical part is worked, then heat treated for hardening, a metal phase comprised mainly of Cu present in the steel has an average size of 0.01 μm or less.

[Claim 11]

Electrical steel sheet remarkably superior in magnetic properties as set forth in any one of claims 1 to 3, 9, and 10 characterized in that, after an electrical part is worked, then heat treated for hardening, an average size of the crystal grains is 3 to 300 μm.

[Claim 12]

Electrical steel sheet remarkably superior in magnetic properties as set forth in any one of claims 1 to 3 and 9 to 11 characterized in that, after an electrical part is worked, then heat treated for hardening, a number density of the metal phase comprised mainly of Cu with a size of 0.01 μm or less in the steel is increased by 10-fold or more.

[Claim 13]

Electrical steel sheet remarkably superior in magnetic properties as set forth in any one of claims 1 to 3 and 9 to 12 characterized in that, after an electrical part is worked, then heat treated for hardening, a tensile strength is increased by 30 MPa or more.

[Claim 14]

Electrical steel sheet remarkably superior in magnetic properties as set forth in any one of claims 1 to 3 and 9 to 13 characterized in that, after an electrical part is worked, then heat treated for hardening, a hardness of the steel is increased by 1.1-fold or more.

[Claim 15]

A method of production of electrical steel sheet remarkably superior in magnetic properties characterized by producing a product sheet from steel comprised of the ingredients as set forth in any of claims 1 to 3 during the process of which making a residence time in a temperature range of 450°C to 700°C in a cooling process from a temperature range of 750°C or more after a final hot rolling in a hot rolling process before cold rolling 300 seconds or less, then cold rolling without holding in a temperature range over 750°C so as to harden the steel by heat treatment after working an electrical part.

[Claim 16]

A method of production of electrical steel sheet remarkably superior in magnetic properties as set forth in claim 15 characterized by holding at 750°C or more for 20

seconds or more in a final heat treatment process after hot rolling and cold rolling, then making the residence time in the temperature range of 450°C to 700°C in the cooling process from the temperature range of 750°C or more 60 seconds or less, then not holding in a temperature range over 750°C so as to harden the steel by heat treatment after working an electrical part.

[Claim 17]

A method of production of electrical steel sheet remarkably superior in magnetic properties characterized by holding electrical steel sheet as set forth in any one of claims 1 to 3 and 9 to 14 or electrical steel sheet produced by a method as set forth in any one of claims 15 and 16 in a temperature range of 300°C to 720°C for 30 seconds or more, then not holding in a temperature range over 700°C for 20 seconds or more to obtain an electrical part so as to harden the steel by heat treatment after working the electrical part.

[Claim 18]

A method of production of electrical steel sheet remarkably superior in magnetic properties as set forth in claim 17 characterized by, as said heat treatment method, making an average cooling rate of a cooling process from the heat treatment temperature to 700°C in heat treatment after working the steel sheet to an electrical part 10°C/seconds or more, holding in a temperature range of 300°C to 720°C for 30 seconds or more, then not holding in a temperature range over 700°C for 20 seconds or more so as to harden the steel by heat treatment after working the electrical part.

[NAME OF DOCUMENT] Specification

[TITLE OF INVENTION] Electrical Steel Sheet Remarkably Superior in Magnetic Properties and Method of Production of Same

[TECHNICAL FIELD]

[0001]

The present invention provides a high strength electrical steel sheet, in particular a high strength non-oriented electrical steel sheet, more particularly relates to a magnetic material for high speed rotary machines which is low in core loss, high in flux density, and high in strength, to a magnetic material for electromagnetic switches which is superior in wear resistance, and to methods for production of the same.

[BACKGROUND ART]

[0002]

Until recently the rotational speed required in rotary devices was at most about 100,000 rpm. Laminated electrical steel sheet was used for the material of rotors. Recently, superhigh speed rotation as high as 200,000 or 300,000 rpm has been demanded. Thus, the centrifugal force applied to the rotor could exceed the strength of the electrical steel sheet. Further, motors of a structure with magnets built into the rotors are increasing in number. The load applied to the material of the rotor itself during rotation of the rotor is therefore becoming large. Thus, in terms of the fatigue strength as well, the strength of the material is becoming an issue in many cases.

[0003]

In other cases, the contact surface of electromagnetic switches is worn during use, and thus magnetic materials superior in not only electromagnetic properties, but also wear resistance are desired.

[0004]

To meet these needs, recently high strength non-oriented electrical steel sheet has been studied. Several proposals have

been made. For example, PLT 1 and PLT 2 propose a material using a slab increased in Si content and further containing one or more of Mn, Ni, Mo, Cr, and other solid solution strengthening components, but the sheet is liable to break easily in rolling and causes less productivity and less yield. Thus the sheet has a room for improvement. Furthermore, since Ni, Mo, and Cr are included in large amounts in the steel, the material becomes extremely expensive.

[0005]

Further, PLT 3 discloses producing high strength non-oriented electrical steel sheet by rapid solidification from a melt containing 2.5% or more of Si. PLT 4 discloses improving the rollability by wrapping a high Si steel containing 2.5% or more Si by low Si steel containing 2.0% or less Si. Since these proposals use special processes, the sheets cannot be produced by the production facilities for conventional electrical steel sheet and therefore are difficult to be produced industrially.

[0006]

With the above methods utilizing solid solute strengthening by solute elements, from the viewpoint of magnetic properties, the saturation magnetic flux density of the material is inherently low, and thus the magnetic flux density of the product sheet is inevitably low. Further, from the viewpoint of crystal structure, the methods inherently refine grain size, so while these are preferable in terms of increasing the strength, there is the problem that the core loss ends up rising.

[0007]

Further, to strengthen a material, utilizing precipitates may also be considered, but precipitates also end up degrading the magnetic properties from the viewpoint of the magnetic flux density and core loss due to the effects of the precipitates themselves and the refining of the crystal structure. In this way, high strength electrical steel sheets have the inherent problem that the magnetic properties originally required are

remarkably degraded.

[0008]

In particular, with materials strengthened by refining grain size or by precipitates, when punched to an article for electrical appliances such as motors etc., in the stress relief annealing (SRA) process for relieving the fabrication stress introduced to the steel sheets, growth of the crystal structure or precipitates occurring while holding the steel at a high temperature is unavoidable and therefore the strength is decreased. Further, use of high strength materials accelerates the wear of the dies when punching the steel into parts for electrical appliances, in particular in the shearing process, so becomes a cause of raising the cost of production of the electrical appliances.

[0009]

PLT 1: Japanese Published Patent Application No. 1-162748

PLT 2: Japanese Published Patent Application No. 61-84360

PLT 3: Japanese Published Patent Application No. 61-87848

PLT 4: Japanese Published Patent Application No. 8-41601

[DISCLOSURE OF THE INVENTION]

[TECHNICAL PROBLEM]

[0010]

In this way, various proposals have been made regarding high strength electrical steel sheet, but the fact is that it is not yet possible to stably produce such steel industrially securing the required magnetic properties and using a conventional electrical steel sheet production facility. Further, there are also many remaining problems such as softening in the stress relief annealing performed after fabrication or the wear of the dies during punching parts for electrical appliances.

[0011]

The object of the present invention is to stably produce, on-line, high strength nonoriented electrical steel sheet which has a high strength of a tensile strength (TS) of 588 N/mm^2 or

more, has wear resistance, and is provided with superior magnetic properties of magnetic flux density and core loss, without greatly changing the cold rollability etc. from that of conventional electrical steel sheet.

[0012]

Further, similarly, an object is to produce an electrical steel sheet which is relatively soft until finishing working the sheet to an electrical part, hardens by heat treatment after working the steel to an electrical part, having high strength and wear resistance and other properties when used as an electrical part, and has excellent magnetic properties.

[0013]

The present invention has been made to solve the above problem and has as its gist the following:

[0014]

(1) Electrical steel sheet remarkably superior in magnetic properties characterized by containing, by mass%, C: 0.040% or less, Si: 0.2 to 3.5%, Mn: 0.05 to 3.0%, P: 0.30% or less, S: 0.040% or less, Al: 2.50% or less, Cu: 0.6 to 8.0%, N: 0.0400% or less, and a balance of Fe and unavoidable impurities and containing in the steel a metal phase comprised of Cu of a diameter of 0.01 μm or less.

[0015]

(2) Electrical steel sheet remarkably superior in magnetic properties as set forth in (1) characterized by further containing, by mass%, one or more of Nb: 0.02% or less, Ti: 0.010% or less, B: 0.010% or less, Ni: 2.5% or less, and Cr: 10.0% or less.

[0016]

(3) Electrical steel sheet remarkably superior in magnetic properties as set forth in (1) or (2) characterized by further containing, by mass%, one or more of Mo, W, Sn, Sb, Mg, Ca, Ce, and Co in a total of 0.5% or less.

[0017]

(4) Electrical steel sheet remarkably superior in

magnetic properties as set forth in any one of (1) to (3) wherein a number density of the metal phase comprised of Cu present in said steel is 20/μm^3 or more.

[0018]

(5) Electrical steel sheet remarkably superior in magnetic properties as set forth in any one of (1) to (4) wherein said steel sheet has an average size of crystal grains of 30 to 300 μm.

[0019]

(6) A method of production of electrical steel sheet remarkably superior in magnetic properties characterized by producing a product sheet from steel comprised of the ingredients as set forth in any of (1) to (3) during the process of which holding it at a temperature range of 300°C to 720°C for 30 seconds or more for heat treatment.

[0020]

(7) A method of production of electrical steel sheet remarkably superior in magnetic properties as set forth in (6), characterized by, as said heat treatment, holding at a temperature range of 300°C to 720°C for 30 seconds or more in a cooling process from a temperature range of 750°C or more in a final heat treatment process.

[0021]

(8) A method of production of electrical steel sheet remarkably superior in magnetic properties as set forth in (6) or (7), characterized by, after the heat treatment, not holding in a temperature range over 800°C for 20 seconds or more.

[0022]

(9) Electrical steel sheet remarkably superior in magnetic properties as set forth in any one of (1) to (3) characterized in that, after an electrical part is worked, then heat treated for hardening, a metal phase comprised mainly of Cu present in the steel has a number density of 20/μm^3.

[0023]

(10) Electrical steel sheet remarkably superior in magnetic properties as set forth in any one of (1) to (3) and (9) characterized in that, after an electrical part is worked, then heat treated for hardening, a metal phase comprised mainly of Cu present in the steel has an average size of 0.01 μm or less.

[0024]

(11) Electrical steel sheet remarkably superior in magnetic properties as set forth in any one of (1) to (3), (9), and (10) characterized in that, after an electrical part is worked, then heat treated for hardening, an average size of the crystal grains is 3 to 300 μm.

[0025]

(12) Electrical steel sheet remarkably superior in magnetic properties as set forth in any one of (1) to (3) and (9) to (11) characterized in that, after an electrical part is worked, then heat treated for hardening, a number density of the metal phase comprised mainly of Cu with a size of 0.01 μm or less in the steel is increased by 10-fold or more.

[0026]

(13) Electrical steel sheet remarkably superior in magnetic properties as set forth in any one of (1) to (3) and (9) to (12) characterized in that, after an electrical part is worked, then heat treated for hardening, a tensile strength is increased by 30 MPa or more.

[0027]

(14) Electrical steel sheet remarkably superior in magnetic properties as set forth in any one of (1) to (3) and (9) to (13) characterized in that, after an electrical part is worked, then heat treated for hardening, a hardness of the steel is increased by 1.1-fold or more.

[0028]

(15) A method of production of electrical steel sheet remarkably superior in magnetic properties characterized by producing a product sheet from steel comprised of the

ingredients as set forth in any of (1) to (3) during the process of which making a residence time in a temperature range of 450°C to 700°C in a cooling process from a temperature range of 750°C or more after a final hot rolling in a hot rolling process before cold rolling 300 seconds or less, then cold rolling without holding in a temperature range over 750°C so as to harden the steel by heat treatment after working an electrical part.

[0029]

(16) A method of production of electrical steel sheet remarkably superior in magnetic properties as set forth in (15) characterized by holding at 750°C or more for 20 seconds or more in a final heat treatment process after hot rolling and cold rolling, then making the residence time in the temperature range of 450°C to 700°C in the cooling process from the temperature range of 750°C or more 60 seconds or less, then not holding in a temperature range over 750°C so as to harden the steel by heat treatment after working an electrical part.

[0030]

(17) A method of production of electrical steel sheet remarkably superior in magnetic properties characterized by holding electrical steel sheet as set forth in any one of (1) to (3) and (9) to (14) or electrical steel sheet produced by a method as set forth in any one of claims 15 and 16 in a temperature range of 300°C to 720°C for 30 seconds or more, then not holding in a temperature range over 700°C for 20 seconds or more to obtain an electrical part so as to harden the steel by heat treatment after working the electrical part.

[0031]

(18) A method of production of electrical steel sheet remarkably superior in magnetic properties as set forth in (17) characterized by, as said heat treatment method, making an average cooling rate of a cooling process from the heat treatment temperature to 700°C in heat treatment after working

the steel sheet to an electrical part 10°C/seconds or more, holding in a temperature range of 300°C to 720°C for 30 seconds or more, then not holding in a temperature range over 700°C for 20 seconds or more so as to harden the steel by heat treatment after working the electrical part.

[ADVANTAGEOUS EFFECTS OF INVENTION]

[0032]

The inventors engaged in various experiments to achieve the above objects. That is, the present invention gives an electrical steel sheet which is high in strength and superior in magnetic properties by a stable method of production not causing sheet breakage or other trouble, by treating steel sheet containing C: 0.040% or less, Si: 0.5 to 3.5%, Mn: 0.05 to 3.0%, P: 0.30% or less, S: 0.040% or less, Al: 2.50% or less, Cu: 0.6 to 8.0%, and N: 0.0400% or less so as to form inside the electrical steel sheet a fine metal phase comprised of Cu even after production process conditions not allowing refinement of the crystal structure.

[0033]

Further, the present invention gives an electrical steel sheet which has excellent workability when being worked into an electrical part and which is hard and excellent in magnetic properties when used as an electrical part, by not allowing the formation of almost any fine metal phase comprised mainly of Cu in the steel sheet in the process of production of the electrical steel sheet under stable process conditions not allowing refinement of the crystal structure and not allowing sheet breakage or other trouble and by causing the formation of a fine metal phase comprised mainly of Cu in the electrical steel sheet in the heat treatment process after working the sheet into the electrical part.

[BEST MODE FOR CARRYING OUT THE INVENTION]

[0034]

First, the composition of ingredients of the high strength electrical steel sheet according to the present invention will

be described.

[0036]

C degrades magnetic properties, so the amount is 0.0040% or less. It is possible to include a higher amount of C up to the slab production stage from the viewpoint of the deoxidation efficiency and to reduce the C to 0.0040% or less by decarburizing annealing after being made into a coil. In this case, from the viewpoint of production costs, it is advantageous to reduce the amount of C by a degasification facility at the molten steel stage. If 0.0020% or less, there is a remarkable effect of reduction of core loss. In the present invention steel, which does not use carbides or other nonmetal precipitates to increase the strength, the C content is preferably 0.0015% or less, and more preferably 0.0010% or less.

[0036]

Si increases volume resistivity of the steel reducing the eddy current to reduce the core loss and increases the tensile strength, but if the amount added is less than 0.2%, that effect is small. In low Si steel, there is almost no embrittlement of the steel. If increasing the Si content, the magnetic properties are not degraded. In particular, it is possible to increase the strength while reducing the core loss. Therefore, the merit of application of the present invention is small, so preferably the invention covers steel containing 1.0% or more, more preferably 2.0% or more, of Si. Further, if over 3.5%, the steel is embrittled and further the magnetic flux density of the product is degraded, so the amount is made 3.5% or less.

[0037]

Mn may be purposely added to improve the steel in strength, but is not particularly required for this purpose in the steel of the present invention utilizing a fine metal phase as the main means for increasing the strength. This is added for the purpose of increasing the volume resistivity or

coarsening the sulfides to promote crystal grain growth reducing the core loss, but since excessive addition reduces the magnetic flux density, the amount is 0.05 to 3.0%. Preferably, the amount is 0.5% to 1.2%.

[0038]

P is an element with a remarkable effect of improving the tensile strength, but like with the above mentioned Mn, in the steel of the present invention, the addition is not necessary. If P is over 0.3%, it causes so severe brittleness that hot rolling, cold rolling, or other processing on an industrial scale is difficult, so the upper limit of P is 0.30%.

[0039]

S easily combines with Cu, an essential element in the steel of the present invention, to form Cu sulfides and thereby has an adverse effect on the formation of the metal phase mainly composed of Cu which is important in the present invention resulting in degrading the strengthening efficiency in some cases. Further, the thus produced sulfides sometimes degrade the magnetic properties, in particular the core loss, so the content of S is preferably as low as possible and is limited to 0.0040% or less. Preferably, it is 0.0020% or less, more preferably 0.0010% or less.

[0040]

Al is usually added as a deoxidizing agent, but it is also possible to add less Al and use Si for deoxidization. In Si-deoxidized steel with an Al content of about 0.005% or less, AlN is not formed, so there is also the effect of reducing the core loss. On the other hand, it is possible to purposely add it to promote coarsening AlN and increase the volume resistivity to reduce the core loss. However, if Al content is over 2.50%, embrittlement becomes a problem, thus the content is 2.50% or less.

[0041]

Cu is an essential element in the present invention. The range for forming a metal phase mainly composed of Cu in the

steel sheet to increase the strength not having an adverse effect on the magnetic properties is limited to 0.6 to 8.0%. More preferably, it is 0.8 to 4.0%. If the Cu is low in content, the effect of increasing the strength becomes small, the heat treatment conditions for obtaining the effect of increasing strength are limited to a narrow range, and the flexibility of control of the production conditions and adjustment of production becomes smaller. Further, if the Cu is high in content, the effect on the magnetic properties becomes larger resulting in remarkably increased core loss. In particular, an amount of Cu over the limit of solid solution in the steel contributes to increased strength as solute Cu, but the strengthening efficiency becomes poor compared with the Cu metal phase of the main object of the present invention. Further, the effect on degradation of the magnetic properties also becomes greater. Further, excessive Cu forms a metal phase in the steel in a not preferable process depending on the heat history. For example, Cu forms a relatively coarse Cu metal phase in a high temperature such as during hot rolling, which acts unpreferably on the formation of the subsequent fine metal phase or has a detrimental effect on the magnetic properties in some cases. The particularly preferable range of Cu is 1.0 to 2.8%. More preferably, it is 1.3 to 2.2%, more preferably 1.5 to 2.0%.

[0042]

N, like C, degrades the magnetic properties, and thus the amount is 0.0040% or less. In the steel of the present invention where no strengthening due to nitrides is expected, the lower the better. If N is 0.0027% or less, the magnetic properties become particularly good. The content is more preferably 0.0022%, still more preferably 0.0015% or less.

[0043]

Almost all elements utilized in the past for increasing the strength in high strength electrical steel sheet not only are problematic in terms of the cost of addition, but also have

some detrimental effect on the magnetic properties, so, in the present invention, they do not really have to be added for the purpose of increasing the strength. When they are purposely added as strengthening elements, due to the relation with rising costs and degradation of magnetic properties, one type or more of Nb, Ti, B, Ni, and Cr may be added but the amounts added are Nb: 0.02% or less, Ti: 0.010% or less, B: 0.010% or less, Ni: 2.5% or less, and Cr: 10.0% or less. In particular, Ni is known to be effective to prevent surface roughening by Cu, the essential element in the steel of the present invention, at hot rolling (Cu scab) and may be purposely added for this purpose as well. B segregates at the crystal grain boundaries and has the effect of suppressing embrittlement due to grain boundary segregation of P, but in the steel of the present invention, embrittlement does not become a particular problem like in the conventional mainly solution strengthened high strength electrical steel sheet, so addition for this purposes is not important. Rather, it may be added for the purpose of improving the magnetic flux density due to the effect of the solute B on the texture. If B is over 0.010%, remarkable embrittlement results, so the upper limit of B is 0.010%.

[0044]

Nb and Ti form fine precipitates of carbides, nitrides, or sulfides in the steel sheet and are elements effective for increasing the strength, but simultaneously cause remarkable degradation of the magnetic properties, in particular the core loss. In the steel of the present invention not utilizing fine carbides, nitrides, etc. as main means for increasing the strength, these are rather harmful elements. For this reason, the upper limits are respectively 0.010%. Preferably, the contents are 0.0050% or less, more preferably 0.0030% or less, whereby it is possible to obtain a good core loss.

[0045]

Ni is known to be effective for the prevention of surface

roughening at hot rolling due to Cu (Cu scab), the essential element in the steel of the present invention, and can be purposely added together with this purpose. Further, it has a relatively small detrimental effect on the magnetic properties and is deemed effective for increasing the strength as well, so is an element often used in high strength electrical steel sheet. Further, it is also effective for improvement of the corrosion resistance, but considering the cost of addition and the detrimental effects on the magnetic properties, the upper limit is preferably 2.5%.

[0046]

Cr is an element added to improve the corrosion resistance or to improve the magnetic properties in high frequency, but again considering the cost of addition and the detrimental effects on the magnetic properties, preferably the upper limit is 10.0%.

[0047]

Further, regarding the other minor elements, not only the amounts unavoidably contained due to the ore, scrap, etc., but the amounts added for various purposes do not impair the effects of the present invention in any way. The unavoidable contents of these elements are usually about 0.005% or less each, but addition in amounts of 0.01% or more is possible for various purposes. In this case as well, considering the balance of the cost and magnetic properties, the steel may contain one or more of Mo, W, Sn, Sb, Mg, Ca, Ce, and Co in a total of 0.5% or less.

[0048]

The steel containing these compositions is produced in the same way as a conventional electrical steel sheet wherein it is melted in a converter, continuously cast into a slab, hot rolled, hot band annealed, cold rolled, final annealed and so on. In addition to these processes, formation of an insulating film or a decarburization process etc. do not impair the effect of the present invention in any way. Further, unusual processes

such as production of thin strip by rapid solidification or continuous casting of thin slabs omitting the hot rolling process have no problems.

[0049]

To form the specific metal phase characteristic of the present invention in the steel sheet, it is effective to go through the following heat history. In the process of production of a product sheet, the sheet is held at a temperature range of 300°C to 720°C for 30 seconds or more. The temperature range is preferably 300 to 650°C, more preferably 350 to 600°C, more preferably 400 to 550°C, more preferably 420 to 500°C. The holding time is related to the holding temperature. Preferably, the lower the temperature, the longer the time. On the other hand, holding at a high temperature for a long time is not preferable. Preferably, it is 650°C or so for 1 minute to 5 hours, at 550°C or so for 3 minutes to 20 hours, and at 450°C or so for 30 minutes or more.

[0050]

Further, after this heat treatment, it is preferable to avoid a process holding the heat treated steel sheet at a temperature range over 800°C for 20 seconds or more.

[0051]

Through the above process, a Cu metal phase of characteristic composition, size, and number density is efficiently formed, the magnetic properties are not impaired much at all, and the strength can be increased. On the other hand, through ordinary heat treatment conditions not aiming at formation of such a metal phase, the majority of the Cu added forms solute Cu or Cu sulfides which are low in strengthening ability and large in effect of degradation of magnetic properties or a relatively coarse Cu metal phase which is small in strengthening ability and large in detrimental effect on the magnetic properties although it is a Cu metal phase.

[0052]

After this heat treatment process, the steel is increased in strength, so performing this heat treatment process after the rolling process and performing it simultaneously with the recrystallization annealing or other heat treatment required for other purposes is advantageous from the viewpoint of productivity. That is, holding in the temperature range of 300°C to 720°C for 30 seconds or more in the final heat treatment process after the cold rolling in the case of cold rolled electrical steel sheet or in the cooling process from the temperature range of 750°C or more in the final heat treatment process after hot rolling in the case of hot rolled electrical steel sheet is preferable.

[0053]

Further, depending on the targeted properties etc., heat treatment is sometimes further added, but in this case, it is preferable not to hold the steel in a temperature range over 800°C for 20 seconds or more. When the temperature and time exceed this in the heat treatment, the formed Cu metal phase resolidifies or conversely aggregates to form a coarse metal phase in some cases.

[0054]

Since the present invention does not utilize strengthening by refinement of crystal structure, there is little degradation of the strength even if performing SRA (stress relief annealing) for relieving the stress introduced into the material and growing the crystal grains to restore and improve the magnetic properties when stamping steel sheet and processing it to motor parts etc. or some other heat treatment performed for other purposes.

[0055]

Further, it is important that the specific metal phase characteristic of the present invention go through the following heat history for formation in the steel sheet after processing to an electrical part. This is to control the holding time in the 300°C to 720°C temperature range and the

subsequent heat history in the process of producing the product sheet and the heat treatment process after being processed to an electrical part.

[0056]

That is, as the heat treatment given to the steel sheet up until the final processing, i.e., punching and fabricating process for utilizing the electrical steel sheet as an electrical part, it is preferable to make the residence time in the temperature range of 450°C to 700°C in the cooling process from the temperature range of 750°C or more to 300 seconds or less for the heat history before the cold rolling after the final hot rolling and 60 seconds or less for the annealing process after cold rolling respectively, and then not holding at a temperature range over 750°C

[0057]

Further, the hardening is performed after the final processing of the electrical steel sheet, i.e. the punching and fabricating process for utilization of the electrical steel sheet for an electrical part. It can be achieved by a heat treatment comprising holding the steel at a temperature range of 300°C to 720°C for 30 seconds or more, then not holding at a temperature range over 700°C. When this heat treatment is performed in the cooling process after a heat treatment at a higher temperature, the average cooling rate of the cooling process down to 700°C before holding in the temperature range of 450°C to 700°C is preferably 10°C/second or more, more preferably the average cooling rate of the cooling process down to 650°C before holding in the temperature range of 500°C to 650°C is 10°C/second or more. Performing this heat treatment in the cooling process such as so-called stress relief annealing process performed for the purpose of relieving the stress introduced against intent in the material when processing is preferable from the viewpoint of the productivity. The maximum peak temperature of 700°C or more before holding in the

temperature range of 300°C to 720°C and the holding time in that temperature range can be determined from only the viewpoint of stress relief and crystal grain growth and do not have any influence on the effects of the present invention.

[0058]

The holding temperature range in the temperature range of 300°C to 720°C for hardening is preferably 300 to 650°C, more preferably 350 to 600°C, further preferably 400 to 550°C, and further preferably 420 to 500°C. The holding time is related to the holding temperature. It is preferable that the lower the temperature, the longer the time. On the other hand, holding at a high temperature for a long time is not preferable. Preferably, if holding at around 650°C for 1 minute to 5 hours, at around 550°C for 3 minutes to 20 hours, and at 450°C or so for 30 minutes or more, a sufficient hardening effect can be obtained.

[0059]

Passing through this process results in efficient formation of the metal phase characteristic in composition, size, and number density in a preferable process and enables hardening without impairing the magnetic properties much at all. The present invention covers steel where the tensile strength increases by 30 MPa or more or the hardness increases by 1.1 times or more by heat treatment for hardening. If the increment in strength or hardness is less than this, probably the steel is already hardened before the heat treatment or the strengthening ability by heat treatment is originally not provided.

[0060]

If the sheet is already hardened before heat treatment, punching into the motor part etc. is performed on a hard material, which is not preferable from the viewpoint of the wear of the dies. Further, when not hardened even with heat treatment, the strength during use as a motor becomes

insufficient and the object of the present invention is not achieved. To obtain a more preferable effect, preferably the increase in tensile strength due to the heat treatment is 60 MPa or more and the increase in hardness is 1.2 times or more, more preferably the increase in tensile strength is 100 MPa or more and the increase in hardness is 1.3 times or more, further preferably the increase in tensile strength is 150 MPa or more and the increase in hardness is 1.4 times or more, and further preferably the increase in tensile strength is 200 MPa or more and the increase in hardness is 1.5 times or more.

[0061]

On the other hand, when passing through normal heat treatment conditions not aiming at formation of a metal phase as controlled in the present invention, depending on the steel composition, sometimes the effect of the formation of a metal phase may be detected, but the majority of the added Cu is present as solute Cu or Cu sulfides or a coarse metal phase of a size of 0.1 μm or more which are low in strengthening ability and large in effect of degradation of the magnetic properties.

[0062]

The metal phase formed in the above way is mainly comprised of Cu. This can be identified by the diffraction parameters of an electron microscope etc. or an attached X-ray analysis apparatus etc. Of course, it may also be identified by chemical analysis or another method. In the present invention, this metal phase mainly comprised of Cu has a size of 0.01 μm or less. If the size is more than this, the efficiency of increasing the strength falls. In this condition, not only a large amount of metal phase becomes necessary, but also the detrimental effect on the magnetic properties becomes greater. From the viewpoint of increasing the strength and the magnetic properties, the diameter is 0.005 μm or less, and more preferably 0.002 μm or less. Note that if less than 0.001 μm, the size becomes too fine and quantification of the metal phase size and amount of metal phase would become difficult even by

the current highest precision analysis equipment, but identification by X-ray analysis equipment and indirect explanation of presence by mechanical properties, hardness, etc. would be possible. The present invention is limited to an electrical steel sheet which contains a considerable amount of Cu and clearly hardens by appropriate heat treatment explained in the present invention. Needless to say, while the present invention describes a "Cu metal phase", this does not limit its form or type.

[0063]

The number density of the Cu metal phase is limited in the possible range in the relation between the Cu content and size of the metal phase, but preferably is 20/μm^3 or more, more preferably 200/μm^3 or more. If made 2000/μm^3 or more, this is extremely effective in the point of increasing the strength. More preferably, it is 20,000/μm^3 or more, still more preferably 200,000/μm^3 or more, further more preferably 2,000,000/μm^3.

[0064]

Control of the metal phase size and number density is extremely important from the viewpoint of achieving both increased strength and holding the magnetic properties. The reason is that these are not only effective on the strength and magnetic properties, but also the way of change of strength and magnetic properties differs when these are changed. That is, it is necessary to control these to the range where the effect of increasing the strength is high and the efficiency of degradation of the magnetic properties is low. For this reason, it is effective to suitably control the temperature and time in the above-mentioned temperature range of 300 to 720°C and the cooling rate immediately before entering this temperature range. The effect is, under normal conditions, like as the formation of general precipitates, if the cooling rate is higher and the temperature is lower, the precipitates are finer

and the metal phase density is higher. A long time leads to a coarser size.

[0065]

Further, in the present invention, since refinement of the crystal structure is not utilized as the main means for increasing the strength, the crystal grain size can be adjusted to the optimal range from the viewpoint of the magnetic properties. The size and density of the metal phase mainly comprised of Cu contributing to the increased strength can be controlled not only by the components, but also mainly by the above-mentioned heat treatment at 720°C or less, so the crystal grain size can be independently controlled from the strength by for example the maximum peak temperature of the recrystallization annealing and the holding time in this temperature range before the heat treatment. Normally, it is controlled to 3 μm to 300 μm by heat treatment at 800°C to 1100°C or so for 20 seconds to 5 minutes or so. More preferably, it is 8 μm to 200 μm. In general, when the frequency of the magnetization current at the time of use of the steel sheet is high, the crystal grains are preferably fine.

[0066]

The present invention has properties completely different from the materials developed in the past for magnetic steel sheet. FIGS. 1 and 2 show the characteristics of the present invention from the viewpoint of the compositions, strength, and magnetic properties of the electrical steel sheet. As shown in FIG. 1, usually electrical steel sheet is produced selectively for magnetic properties mainly by the Si content. From the viewpoint of the magnetic properties, Si is usually added to increase the electrical resistance of the material and to reduce the core loss, but since Si also has a strong solid solution strengthening effect, the strength is also increased in high Si, i.e. high grade, materials. However, if the amount of Si is over 3% or the combination of Si, Al, Mn and other

strengthening elements exceeds 6%, the rollability remarkably degrades and production of the steel sheet becomes difficult in conventional production process.

[0067]

As the means for avoiding rolling, the method of directly obtaining a thin film from molten state steel by rapid solidification has been proposed, but there are limits to practical use of this from the viewpoint of cost and properties. For this reason, a high strength material equivalent to 3% Si steel or more is strengthened by the precipitates mainly comprised of carbonitrides accompanying addition of Nb etc. and the refinement of the crystal structure also involving low temperature annealing. However, such carbonitrides or a fine crystal structure is not preferable from the viewpoint of the magnetic properties, in particular the core loss as shown in FIG. 2, wherein a great increase in the core loss is unavoidable.

[0068]

The present invention disperses a different metal phase in a steel sheet so as to increase the strength, which is different from the conventional high strength steels. This metal phase can be controlled independently of the crystal grain size, that is, formation of the metal phase can be controlled in a lower temperature range of about 300 to 720°C which is different from the temperature range where crystal grain growth occurs, that is, about 750°C or more. Therefore the present invention has a greater flexibility from the viewpoint of controlling the strength and magnetic properties independently and thus, as shown in FIG. 2, the strength can be increased without degrading the magnetic properties very much.

[0069]

Further, as shown in FIG. 1, by applying this technology to low Si steel, it becomes possible to obtain a material with a higher magnetic flux density than conventional one. This is considered to be as follows: because most of the solid solution

strengthening elements including typically used Si, Al, Mn reduce the saturation magnetic flux density of the steel, lowered magnetic flux density in a specific magnetic field is unavoidable, but in the present invention, the Cu metal phase used for increasing the strength has an extremely small effect in reducing the saturation magnetic flux density. Furthermore, it is considered that the Cu metal phase does not become a barrier for magnetic domain wall motion compared with other precipitates such as carbonitrides. This is effective for improvement of the magnetic properties especially in a low magnetic field.

[0070]

Note that the effects of the present invention are not affected by the existence and type of surface coating normally formed on the surface of the electrical steel sheet or by the production process, so that it can be applied to non-oriented or grain-oriented electrical steel sheet.

[0071]

The applications are also not particularly limited. The sheet can be applied not only to the rotors of motors used in home electric appliances or automobiles etc., but also to all other applications where both strength and magnetic properties are required.

[EXAMPLES]

[0072]

(Example 1)

The steel compositions shown in Table 1 were made into 250 mm thick slabs. The final sheets were produced by basically the following process. The basic process conditions were a slab heating temperature of 1100°C, a final hot band thickness of 2.0 mm, a coiling temperature of 500°C in hot rolling, a final sheet thickness of 0.5 mm in the cold rolling, and a recrystallization annealing temperature of 850°C. Each product sheet was measured for mechanical properties using a JIS No. 5 test piece and for magnetic flux density B_{10} and core loss

$W_{10/400}$ using a 55 mm square SST test. The mechanical properties and magnetic properties were calculated as the average of the values of the rolling direction and transverse direction of the coil. The results are shown in Table 2 (continuation of Table 1).

[0073]

As clear from the results shown in Table 2, the samples produced by the conditions of the present invention are good in rollability at the cold rolling process, hard, and superior in magnetic properties.

[0074]

[Table 1]

	Ingredients (mass%)									Precipitation process		High temperature treatment after precipitation	
	C	Si	Mn	P	S	Al	N	Cu	Others	Temp. (°C)	Holding time (min)	Temp. (°C)	Holding time (s)
1	0.0020	1.1	0.32	0.021	0.0030	0.002	0.0024	0.006	-	-	-	-	-
2	0.0049	1.1	0.33	0.121	0.0023	0.003	0.0039	0.01	Ni: 1.5 Nb: 0.03	-	-	-	-
3	0.0008	1.2	0.13	0.016	0.0023	0.001	0.0023	0.93	-	650	60	-	-
4	0.0015	1.3	0.32	0.015	0.0010	0.002	0.0017	1.41	-	700	120	-	-
5	0.0016	1.1	0.30	0.020	0.0026	0.005	0.0015	1.14	-	550	10	-	-
6	0.0022	1.2	0.44	0.021	0.0021	0.002	0.0014	1.40	Ni: 1.3	500	60	-	-
7	0.0022	1.2	0.44	0.021	0.0021	0.002	0.0014	1.33	Ti: 0.03	450	120	-	-
8	0.0022	1.2	0.44	0.021	0.0021	0.002	0.0014	1.91	-	400	150	-	-
9	0.0027	1.2	0.80	0.020	0.0005	0.003	0.0020	2.24	-	300	1000	-	-
10	0.0018	1.3	0.30	0.016	0.0013	0.002	0.0022	8.53	-	500	120	-	-

[0075]

[Table 2]

	Metal phase composed of Cu		Crystal grain average size (μm)	Mechanical properties				Magnetic properties		Cold roll-ability	Evaluation
	Average size (μm)	Number density (/μm)		Hardness Hv	YP (Mpa)	TS (MPa)	El (%)	B10 (T)	W10/400 (W/kg)		
1	-	-	100	140	276	457	35	1.63	35.0	V.good	D
2	-	-	25	240	518	682	14	1.30	52.9	Fair	D
3	0.35	0.2	120	216	448	573	32	1.62	37.3	V.good	D
4	0.22	2.5	160	250	533	623	25	1.60	34.8	V.good	D
5	0.008	30	180	245	545	690	28	1.60	32.5	V.good	C
6	0.005	200	90	265	588	756	19	1.62	34.1	V.good	B
7	0.002	2000	70	288	576	699	25	1.58	36.1	V.good	B
8	0.001	400	120	276	622	789	26	1.60	29.7	V.good	A
9	0.001	>10000	100	310	788	923	20	1.57	37.2	V.good	A
10	0.35	2.3	70	249	547	704	25	1.40	48.8	Good	D

A. Developed steel (very good)
B. Developed steel (good)
C. Developed steel (slightly good)
D. Comparative steel

V.good: Very good (no problem at all)
Good: Good (fine adjustment required, but no problem)
Fair: Fair (sheet runnable if adjusting conditions)
Poor: Poor (large danger of sheet breakage)

[0076]

(Example 2)

The steel compositions shown in Table 3 was made into 250 mm thick slabs. Final sheets were produced by basically the following process. The basic process conditions were a slab heating temperature of 1100°C, a final hot band thickness of 2.0 mm, a coiling temperature of 700°C in the hot rolling, a hot band annealing of 980°C temperature for 30 seconds, a final sheet thickness of 0.2 mm in the cold rolling, and a recrystallization annealing of 1000°C. Each product sheet was measured for mechanical properties using a JIS No. 5 test piece and for magnetic flux density B_{50} and core loss $W_{15/50}$ using a 55 mm square SST test. The mechanical properties and magnetic properties were calculated as the average of the values of the rolling direction and transverse direction of the coil. The results are shown in Table 4 (continuation of Table 3).

[0077]

As clear from the results shown in Table 4, the samples produced by the conditions of the present invention are good in rollability at the cold rolling process, hard, and superior in magnetic properties.

[0078]

[Table 3]

	Ingredients (mass%)									Precipitation process		High temperature treatment after precipitation	
	C	Si	Mn	P	S	Al	N	Cu	Others	Temp. (°C)	Holding time (min)	Temp. (°C)	Holding time (s)
11	0.0021	3.1	0.18	0.014	0.0005	0.51	0.0018	0.0008	-	-	-	-	-
12	0.0088	3.1	0.20	0.014	0.0017	0.56	0.0012	0.03	Ni: 2.5 Nb: 0.03	-	-	-	-
13	0.0009	2.8	0.19	0.005	0.0024	0.57	0.0011	0.97	-	750	10	-	-
14	0.0021	3.1	0.20	0.007	0.0012	0.52	0.0006	1.37	-	700	2	-	-
15	0.0021	3.1	0.21	0.005	0.0026	0.54	0.0011	1.66	-	600	5	-	-
16	0.0011	2.9	0.19	0.014	0.0029	0.56	0.0008	1.52	Cr: 4.5	500	10	1050	30
17	0.0021	2.5	0.16	0.004	0.0023	0.52	0.0023	2.31	-	450	120	-	-
18	0.0013	2.5	0.24	0.012	0.0028	0.58	0.0010	1.85	-	400	600	-	-
19	0.0009	2.8	0.21	0.008	0.0012	0.55	0.0013	3.12	-	350	1800	100	40
20	0.0015	3.1	0.18	0.009	0.0023	0.55	0.0011	8.72	-	450	120	-	-

[0079]

[Table 4]

	Metal phase composed of Cu		Crystal grain average size (μm)	Mechanical properties				Magnetic properties		Cold roll-ability	Evaluation
	Average size (μm)	Number density (/μm)		Hardness Hv	YP (Mpa)	TS (MPa)	El (%)	B50 (T)	W15/50 (W/kg)		
11	-	-	120	176	390	530	17	1.68	2.4	Fair	D
12	-	-	20	320	804	833	14	1.64	10.6	Poor	D
13	0.55	0.2	210	315	883	881	13	1.69	4.4	Good	D
14	0.01	1.2	130	315	789	905	13	1.67	3.2	Fair	C
15	0.004	2000	110	309	738	938	14	1.65	2.5	Fair	B
16	0.008	2000	95	397	944	1119	11	1.69	2.5	Good	B
17	0.002	>10000	210	355	790	980	14	1.70	2.4	V.good	A
18	0.001	5000	180	379	1055	1205	10	1.71	2.1	V.good	A
19	0.003	600	130	325	856	898	16	1.67	2.7	Fair	B
20	0.25	200	60	267	690	793	20	1.53	3.8	Poor	D

A. Developed steel (very good)
B. Developed steel (good)
C. Developed steel (slightly good)
D. Comparative steel

V.good: Very good (no problem at all)
Good: Good (fine adjustment required, but no problem)
Fair: Fair (sheet runnable if adjusting conditions)
Poor: Poor (large danger of sheet breakage)

[0080]

(Example 3)

The steel compositions shown in Table 5 were made into 250 mm thick slabs. Final sheets were produced by basically the following process. The basic process conditions were a slab heating temperature of 1100°C, a final hot band thickness of 2.0 mm, a coiling temperature of 300°C or less in hot rolling, a final sheet thickness of 0.2 mm in cold rolling, and a recrystallization annealing temperature of the temperature or more at which the recrystallization occurred. After this, to simulate precipitation heat treatment after punching, a heat treatment at about 750°C was employed to control texture and precipitation of the metal phase. When the heat treatment simulates stress relief annealing, the precipitation heat treatment was employed in the cooling process after a heat treatment at 750°C for 2 hours. Each sheet before and after the heat treatments was measured for mechanical properties using a JIS No. 5 test piece and for magnetic flux density B_{10} and core loss $W_{10/400}$ using a 55 mm square SST test. The mechanical properties and magnetic properties were calculated as the average of the values of the rolling direction and the transverse direction of the coil. As for punching die wear, a newly produced punching die was used to punch the steel sheet and the wear was evaluated based on the change of the height of the burrs on the steel sheet in relation to the number of punching. Die with large wear results in large burrs of the steel sheet in a relatively small number of punching. The results are shown in Table 6 (continuation of Table 5).

[0081]

As clear from the results shown in Table 6, the samples produced under the conditions of the present invention are soft and thus are good in rollability in the cold rolling process and result in small wear of the punching die before the precipitation heat treatment and become hard and superior in magnetic properties after precipitation treatment.

[0082]

[Table 5]

	Ingredients (mass%)									Precipitation process		Precipitation heat treatment			Metal phase composed of Cu before prec. heat treatment	
	C	Si	Mn	P	S	Al	N	Cu	Others	Hot rolling *1	Hot rolling *2	Process	Temp. (°C)	Holding time (min)	Average size (μm)	Number density ($/\mu m^3$)
21	0.0025	1.11	0.48	0.044	0.0016	0.004	0.0008	0.007	-	100	30	A	500	60	-	-
22	0.0061	1.02	0.50	0.076	0.0014	0.002	0.0016	0.02	Ni:2.5 Nb:0.03	30	30	A	500	60	-	-
23	0.0007	1.11	0.49	0.052	0.0007	0.002	0.0006	0.53	-	30	20	A	500	60	-	-
24	0.0016	1.03	0.46	0.048	0.0017	0.001	0.0025	0.89	-	60	60	A	500	60	0.11	0.1
25	0.0006	1.12	0.46	0.052	0.0005	0.004	0.0020	0.64	-	30	5	A	500	60	-	-
26	0.0021	1.01	0.50	0.061	0.0016	0.004	0.0028	0.88	-	40	5	A	500	60	0.004	0.01
27	0.0023	1.16	0.48	0.069	0.0013	0.004	0.0020	1.14	-	20	30	B	500	80	-	-
28	0.0013	1.08	0.53	0.043	0.0017	0.003	0.0017	1.40	Ca:0.005	60	30	A	500	60	-	-
29	0.0007	1.16	0.52	0.072	0.0011	0.004	0.0009	1.33	Ti:0.03	20	20	B	650	1	-	-
30	0.0013	1.13	0.52	0.046	0.0015	0.003	0.0027	1.52	-	900	300	A	400	300	0.007	2000
31	0.0006	1.17	0.52	0.071	0.0015	0.005	0.0021	1.83	-	30	20	A	400	300	0.03	0.15
32	0.0020	1.11	0.49	0.066	0.0007	0.001	0.0025	2.25	-	20	10	A	350	300	0.06	0.2
33	0.0021	1.09	0.50	0.064	0.0013	0.001	0.0012	8.64	-	30	30	A	350	300	1.3	0.03

A. Cooling process in stress relief annealing process after working to motor
B. Only precipitation heat treatment after working to motor

*1. Residence time at temperature range of 450 to 700°C in cooling process after final rolling of hot rolling (sec)
*2. Residence time at temperature range of 450 to 700°C in cooling process in final rolling after hot rolling (sec)

[0083]

[Table 6]

	After precipitation heat treatment of metal phase composed of Cu		Crystal grain average size (μm)	Mechanical properties before and after precipitation heat treatment and changes in same						Magnetic properties after precipitation heat treatment		Cold roll-ability	Wear of stamping die	Eval-uation
				Before	After	Com.	Before	After	Comp.					
	Average size (μm)	Number density (/μm^3)		Hardness HV	Hardness Hv	Hardness Hv	TS (MPa)	TS (MPa)	TS (MPa)	B10 (T)	W10/400 (W/kg)			
21	-	-	100	121	118	0.97	391	361	-30	1.65	10.2	V.good	Good	C
22	-	-		200	154	0.77	630	465	-165	1.25	31.3	Fair	Poor	C
23	0.002	0.02		130	125	0.96	398	387	-11	1.60	15.5	V.good	Good	C
24	0.11	0.1	120	118	120	1.02	378	363	-15	1.61	11.2	V.good	Good	C
25	0.004	10	150	133	166	1.25	422	502	80	1.69	11.8	V.good	Good	B
26	0.002	200	120	122	212	1.74	408	579	171	1.63	8.3	V.good	Good	A
27	0.004	200	100	146	241	1.65	443	616	173	1.65	9.2	V.good	Good	A
28	0.001	3000	70	123	187	1.51	386	538	152	1.62	9.2	V.good	Good	A
29	0.003	1000	70	149	211	1.42	457	600	143	1.59	11.4	V.good	Good	B
30	0.008	4000	50	175	178	1.02	507	506	-1	1.49	12.1	Poor	Poor	C
31	0.001	>10000	80	150	251	1.68	454	692	238	1.62	12.4	V.good	Good	A
32	0.002	6000	70	135	277	2.05	440	784	344	1.56	12.0	V.good	Good	A
33	1.05	0.11	70	135	146	1.08	420	420	0	1.43	24.5	Good	Good	C

A. Developed steel (very good)
B. Developed steel (good)
C. Comparative steel

Good: Small
Poor: Large

V.good: Very good (no problem at all)
Good: Good (fine adjustment required, but no problem)
Fair: Fair (sheet runnable if adjusting conditions)
Poor: Poor (large danger of sheet breakage)

[0084]

(Example 4)

Steels of the compositions shown in Table 7 were made into 250 mm thick slabs. Final sheets were produced by basically the following process. The basic process conditions were a slab heating temperature of 1100°C, a final hot band thickness of 2.0 mm, a coiling temperature of 300°C or less in hot rolling, a hot band annealing of 980°C and 30 seconds, a final sheet thickness of 0.35 mm in cold rolling and a recrystallization annealing temperature of the temperature or more at which the recrystallization occurred. After this, to simulate precipitation heat treatment after punching, a heat treatment at about 750°C was employed to control texture and precipitation of the metal phase. When the heat treatment simulates stress relief annealing, the precipitation heat treatment was employed in the cooling process after a heat treatment at 750°C for 2 hours. Each sheet before and after the heat treatments was measured for mechanical properties using a JIS No. 5 test piece and for magnetic flux density B_{50} and core loss $W_{15/50}$ using a 55 mm square SST test. The mechanical properties and magnetic properties were calculated as the average of the values of the rolling direction and the transverse direction of the coil. As for punching die wear, a newly produced punching die was used to punch the steel sheet and the wear was evaluated based on the change of the height of the burrs on the steel sheet in relation to the number of punchings. A die with large wear results in large burrs of the steel sheet in a relatively small number of punchings. The results are shown in Table 8 (continuation of Table 7).

[0085]

As clear from the results shown in Table 8, the samples produced under the conditions of the present invention are soft and thus are good in rollability in the cold rolling process and result in small wear of the punching die before the

precipitation heat treatment and become hard and superior in magnetic properties after the precipitation treatment.

[0086]

[Table 7]

	Ingredients (mass%)									Precipitation process		Precipitation heat treatment			Metal phase composed of Cu before prec. heat treatment	
	C	Si	Mn	P	S	Al	N	Cu	Others	Hot rolling *1	Hot rolling *2	Process	Temp. (°C)	Holding time (min)	Average size (μm)	Number density (/μm^3)
34	0.0017	2.94	0.28	0.014	0.0010	0.47	0.0018	0.03	-	40	20	B	550	10	-	-
35	0.0065	2.86	0.34	0.013	0.0015	0.49	0.0025	0.03	Ni:2.5 Nb:0.03	30	10	B	550	10	-	-
36	0.0024	2.86	0.34	0.014	0.0007	0.54	0.0022	0.48	-	100	20	B	550	10	-	-
37	0.0016	2.85	0.28	0.015	0.0014	0.54	0.0013	0.66	-	30	30	B	550	10	-	-
38	0.0013	2.88	0.34	0.019	0.0017	0.46	0.0011	0.96	-	30	20	B	550	10	0.05	0.02
39	0.0011	2.88	0.31	0.017	0.0004	0.50	0.0021	1.16	-	120	20	B	550	10	0.04	0.01
40	0.0011	2.88	0.31	0.017	0.0004	0.50	0.0021	1.16	-	120	20	A	550	20	0.04	0.03
41	0.0024	2.89	0.27	0.018	0.0016	0.53	0.0016	1.40	-	30	5	A	550	20	0.12	0.04
42	0.0023	2.91	0.25	0.011	0.0012	0.55	0.0028	1.43	Nb:0.03	20	10	B	600	5	-	-
43	0.0014	2.92	0.31	0.016	0.0007	0.45	0.0022	1.38	Ca:0.005	60	20	A	450	900	0.02	0.03
44	0.0005	2.87	0.29	0.014	0.0013	0.54	0.0022	1.60	-	20	300	B	450	300	0.29	0.2
45	0.0005	2.87	0.29	0.014	0.0013	0.54	0.0022	1.60	-	900	10	A	450	300	0.35	0.2
46	0.0014	2.90	0.25	0.018	0.0005	0.52	0.0016	1.95	Ni:2.5	20	10	A	450	150	0.04	0.04
47	0.0010	2.91	0.31	0.013	0.0006	0.50	0.0028	2.89	-	20	5	B	350	120	0.06	0.02
48	0.0023	2.91	0.32	0.019	0.0015	0.48	0.0029	8.33	-	20	30	A	450	60	1.7	0.02

A. Cooling process in stress relief annealing process after working to motor
B. Only precipitation heat treatment after working to motor

*1. Residence time at temperature range of 450 to 700°C in cooling process after final rolling of hot rolling (sec)
*2. Residence time at temperature range of 450 to 700°C in cooling process in final rolling after hot rolling (sec)

[0087]

[Table 8]

	After precipitation heat treatment of metal phase composed of Cu		Crystal grain average size (μm)	Mechanical properties before and after precipitation heat treatment and changes in same						Magnetic properties after precipitation heat treatment		Cold roll-ability	Wear of stamping die	Eval-uation
				Before	After	Com.	Before	After	Comp.					
	Average size (μm)	Number density (/μm^3)		Hardness HV	Hardness Hv	Hardness Hv	TS (MPa)	TS (MPa)	TS (MPa)	B10 (T)	W10/400 (W/kg)			
34	-	-	150	176	182	1.04	530	530	0	1.65	2.5	V.good	Good	C
35	-	-	60	250	222	0.89	768	662	-106	1.20	8.7	Fair	Poor	C
36	0.01	0.1	130	168	166	0.99	530	552	22	1.68	2.7	V.good	Good	C
37	0.003	0.1	130	168	193	1.15	515	611	96	1.68	2.5	V.good	Good	B
38	0.002	20	170	174	220	1.27	543	710	167	1.71	2.2	V.good	Good	B
39	0.003	3000	130	171	255	1.49	529	783	254	1.69	2.3	V.good	Good	A
40	0.004	1000	120	171	267	1.57	529	779	250	1.68	2.5	V.good	Good	A
41	0.004	80	120	169	224	1.33	521	609	88	1.66	2.4	V.good	Good	B
42	0.001	>10000	90	167	280	1.68	518	816	298	1.62	2.7	V.good	Good	A
43	0.002	100	180	179	311	1.74	531	857	326	1.66	2.4	V.good	Poor	A
44	0.02	70	100	283	280	0.99	825	818	-7	1.64	3.9	Poor	Poor	C
45	0.006	100	100	218	256	1.17	690	744	54	1.64	3.0	Fair	Good	B
46	0.003	4000	140	230	350	1.52	710	1150	440	1.65	2.2	Good	Good	B
47	0.002	>10000	150	171	358	2.09	515	1155	640	1.67	2.2	V.good	Good	A
48	0.76	0.05	120	230	245	1.07	654	705	51	1.40	6.0	Good	Good	C

A. Developed steel (very good)
B. Developed steel (good)
C. Comparative steel

Good: Small
Poor: Large

V.good: Very good (no problem at all)
Good: Good (fine adjustment required, but no problem)
Fair: Fair (sheet runnable if adjusting conditions)
Poor: Poor (large danger of sheet breakage)

[INDUSTRIAL APPLICABILITY]

[0088]

As explained above, the present invention enables stable production of a high strength electrical steel sheet which is hard and superior in magnetic properties. Due to this, it becomes possible to secure strength, fatigue strength, and wear resistance without degrading the magnetic properties, and so greater efficiency, smaller size, superlonger lifetime, etc. of superhigh speed motors, motors incorporating magnets in rotors, and electromagnetic switch materials can be achieved.

[BRIEF DESCRIPTION OF THE DRAWINGS]

[0089]

[FIG. 1] is a schematic drawing of the relationship between the Si content and tensile strength of the steel sheet of the present invention.

[FIG. 2] is a schematic drawing of the relationship between the tensile strength and core loss of the steel sheet of the present invention.

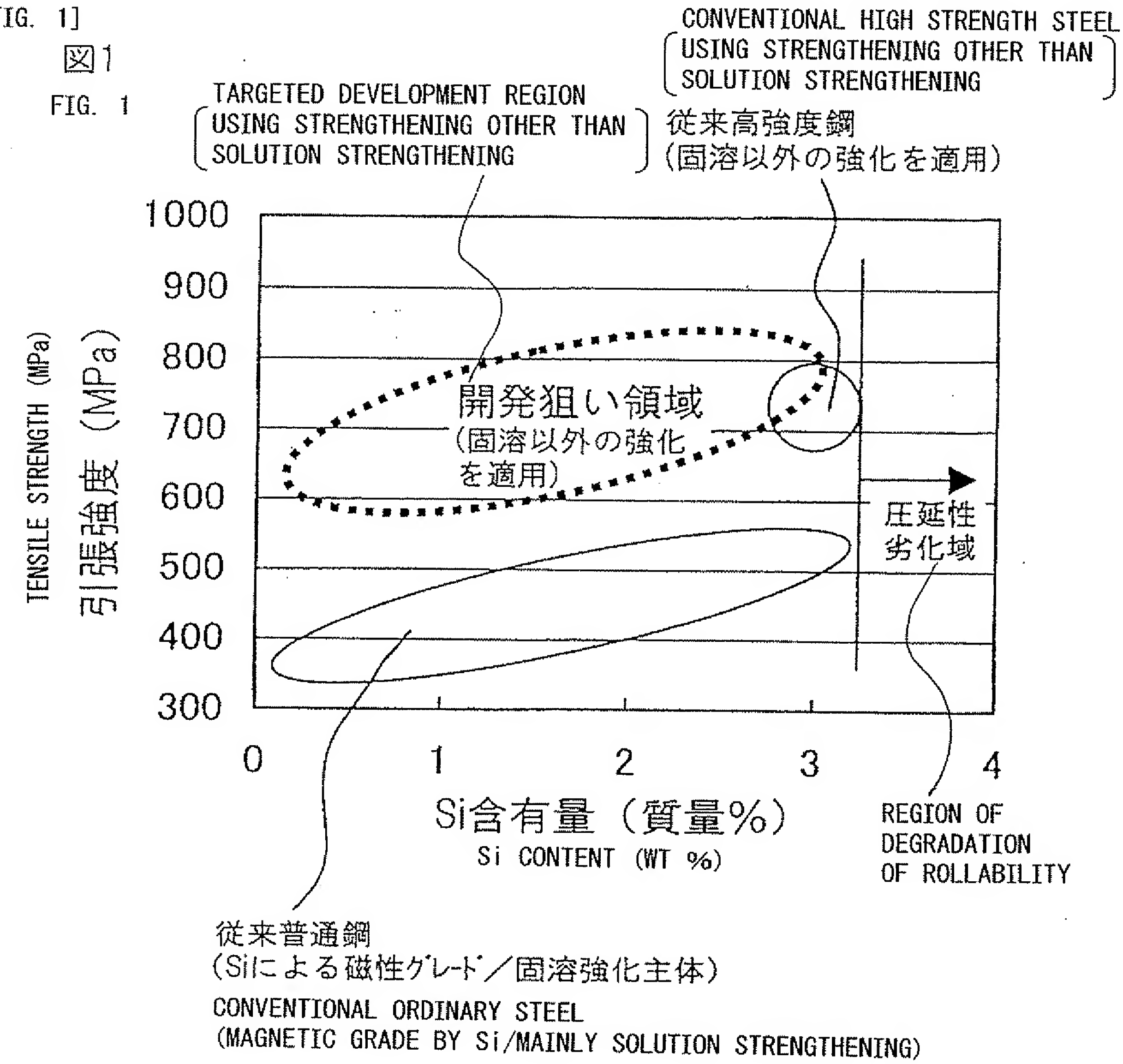
【書類名】図面　[NAME OF DOCUMENT]　DRAWINGS

【図１】

[FIG. 1]

図1

FIG. 1



【図２】[FIG. 2]

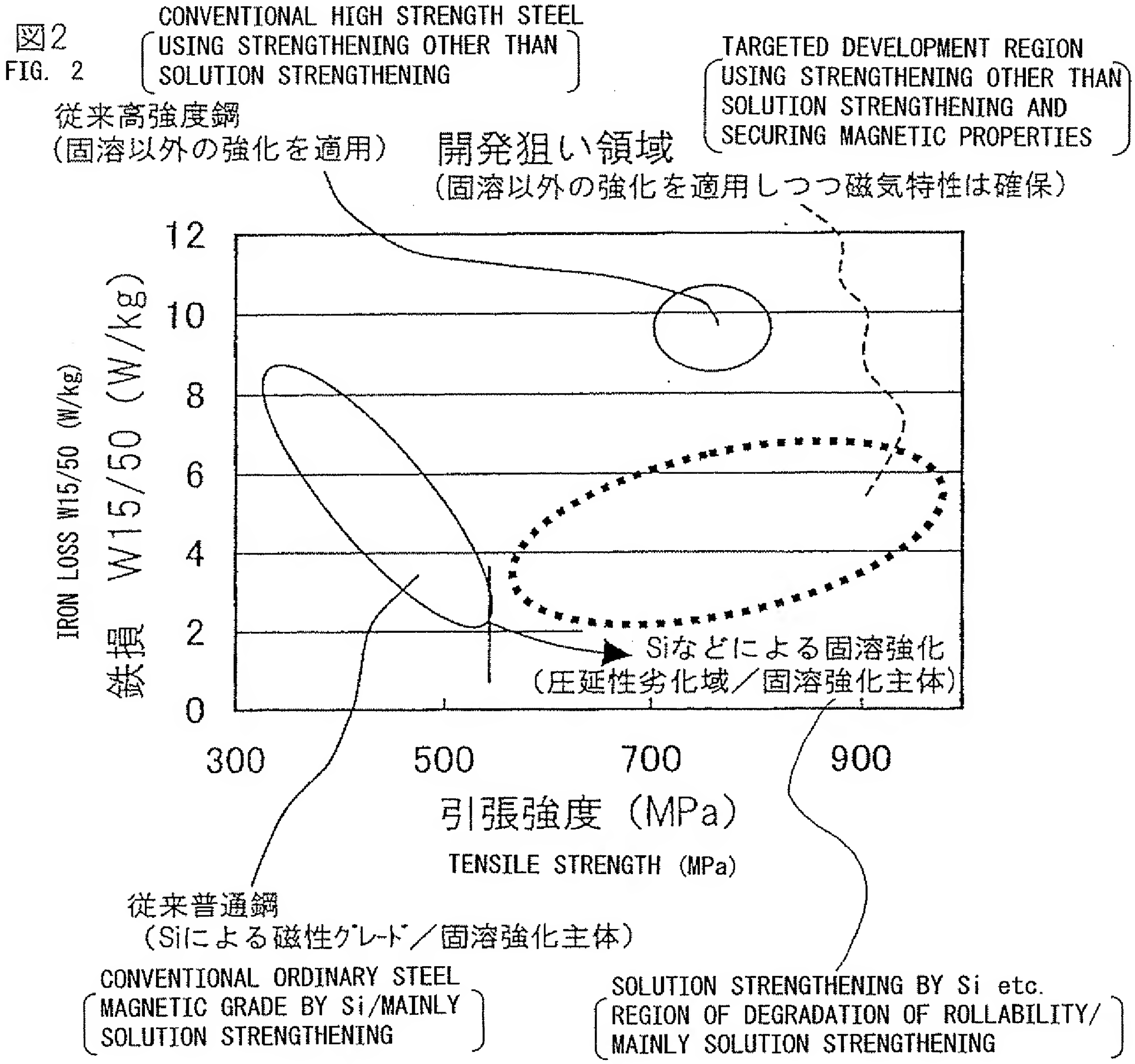


図2
FIG. 2
CONVENTIONAL HIGH STRENGTH STEEL
(USING STRENGTHENING OTHER THAN SOLUTION STRENGTHENING)
従来高強度鋼
(固溶以外の強化を適用)
TARGETED DEVELOPMENT REGION
(USING STRENGTHENING OTHER THAN SOLUTION STRENGTHENING AND SECURING MAGNETIC PROPERTIES)
開発狙い領域
(固溶以外の強化を適用しつつ磁気特性は確保)
IRON LOSS W15/50 (W/kg)
鉄損 W15/50 (W/kg)
12
10
8
6
4
2
0
300
500
700
900
Siなどによる固溶強化
(圧延性劣化域／固溶強化主体)
引張強度 (MPa)
TENSILE STRENGTH (MPa)
従来普通鋼
(Siによる磁性ｸﾞﾚｰﾄﾞ／固溶強化主体)
CONVENTIONAL ORDINARY STEEL
(MAGNETIC GRADE BY Si/MAINLY SOLUTION STRENGTHENING)
SOLUTION STRENGTHENING BY Si etc.
(REGION OF DEGRADATION OF ROLLABILITY/ MAINLY SOLUTION STRENGTHENING)

[NAME OF DOCUMENT] Abstract

[ABSTRACT]

[PROBLEM] The object is to stably produce, on-line, high strength nonoriented electrical steel sheet which has a high strength of a tensile strength TS of 588 N/mm^2 or more, has wear resistance, and is provided with superior magnetic properties of magnetic flux density and core loss, without greatly changing the cold rollability etc. from that of conventional electrical steel sheet.

[SOLUTION] High strength electrical steel sheet characterized by containing, by mass%, C: 0.040% or less, Si: 0.2 to 3.5%, Mn: 0.05 to 3.0%, P: 0.30% or less, S: 0.040% or less, Al: 2.50% or less, Cu: 0.6 to 8.0%, and N: 0.0400% or less and containing in the steel a metal phase comprised of Cu of a diameter of 0.01 μm or less. As the method of production of the same, heat treatment is performed which holds the steel at the 300°C to 720°C temperature region for 30 seconds or more.

[SELECTED DRAWING] FIG. 1